# The Architecture of Galileo System Time

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# Galileo System Time and Timing User Specs

| Parameter | Specification |
|---|---|
| GST – TAI time offset uncertainty<br>*(relative to TAI, 2σ)* | **<28 ns** |
| GST Limits<br>*(expressed as a time offset relative to TAI, 95% of the time over any yearly time interval)* | **< 50 ns** |

related to accuracy

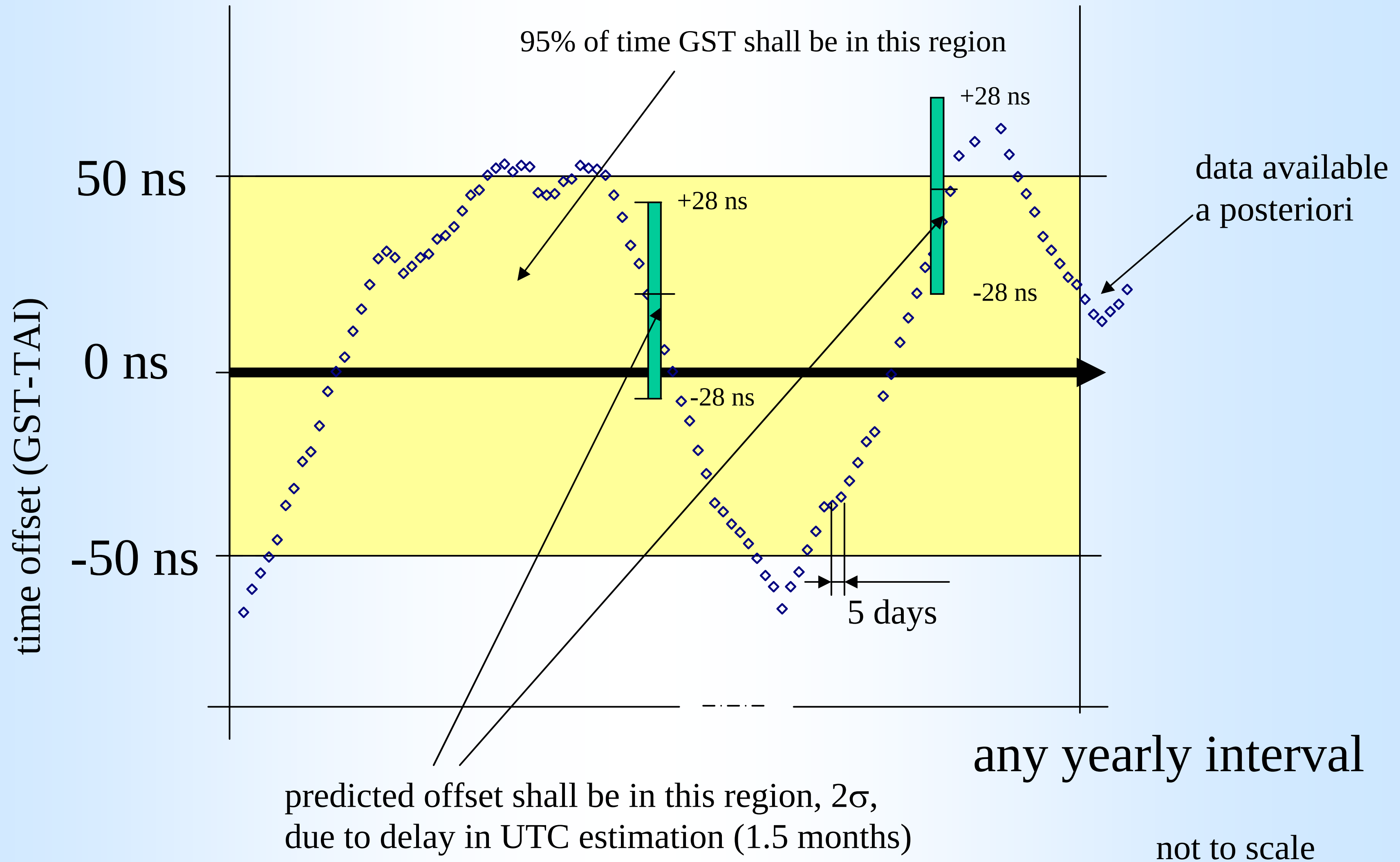
Drivers for:
→Performance
→Interoperability

related to steering

| User Performance | Specification |
|---|---|
| Frequency Accuracy<br>(expressed as a normalised frequency offset relative to UTC, 2σ, over any 24 h interval) | $< 3 \times 10^{-13}$ |
| User UTC determination uncertainty<br>(2σ) | < 30 ns |

accuracy + other user contributions

# Galileo System Time vs. TAI



# Timekeeping Function

Twofold:

Core System

Precision Timing Facility (PTF)

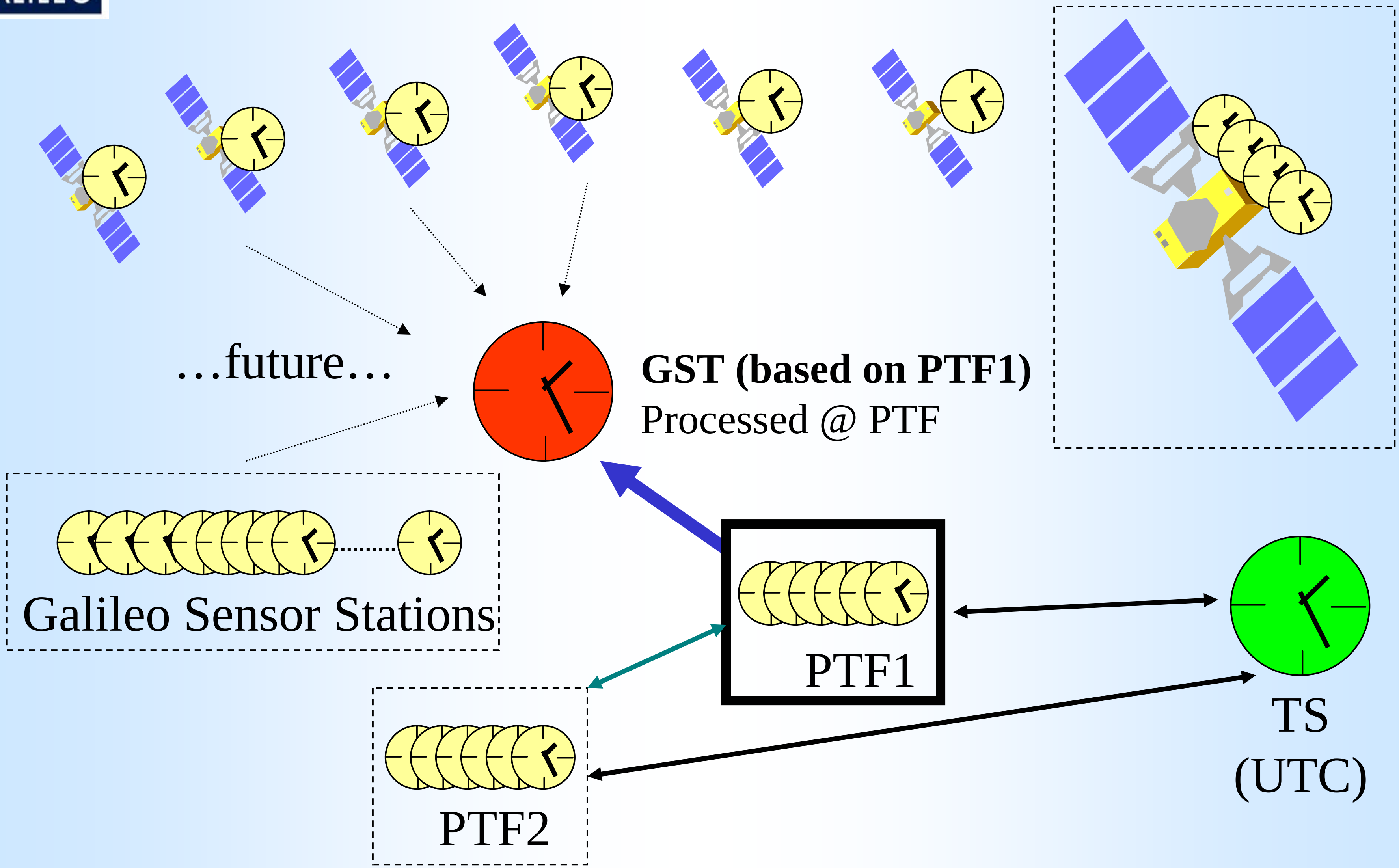
→ Navigation Timekeeping:
critical for navigation mission, needed for orbit determination/ prediction and clock synchronisation

→ Metrological Timekeeping, not critical, but needed to steer GST towards TAI and to provide the UTC timing (dissemination) service

External

Time Service

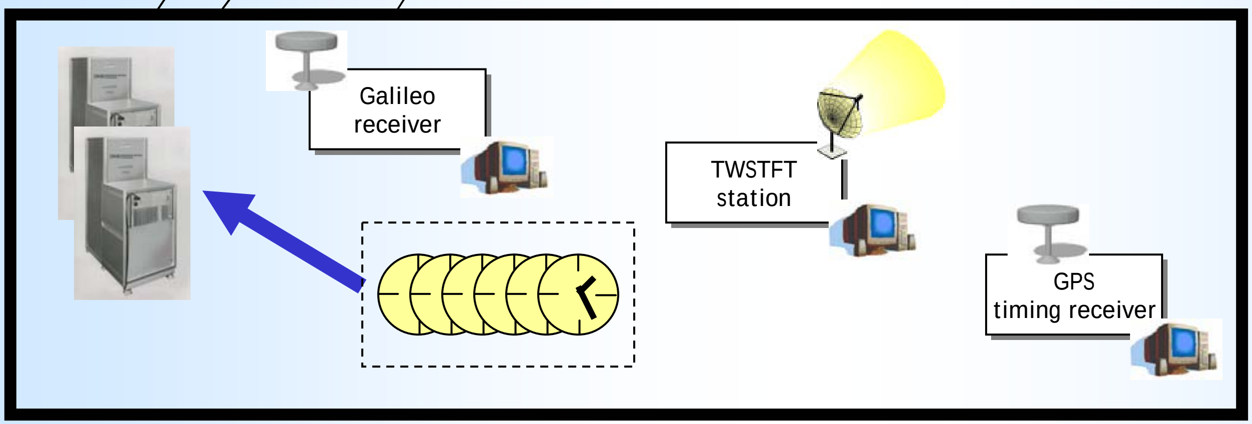
# Setting-up Galileo System Time



# Access to Galileo System Time

Internal use:

- 1 pps PHYSICAL OUTPUT
- 5 or 10 MHz
- Pseudo-Range referenced to GST
- TWSTFT data
- Time codes



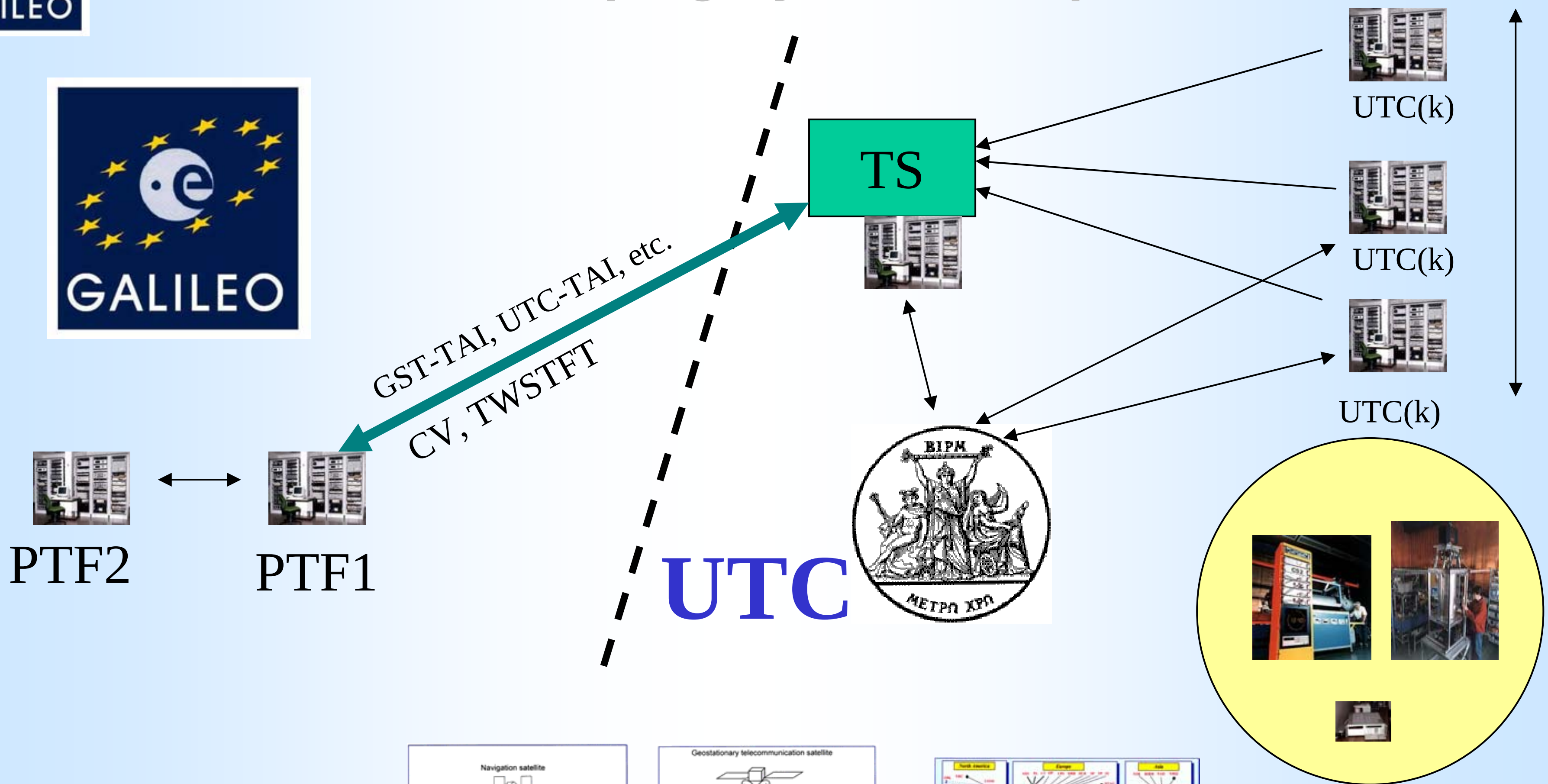

User access:

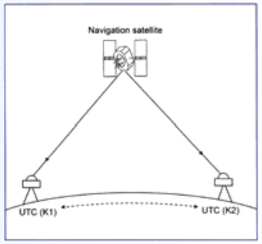
- via SIS

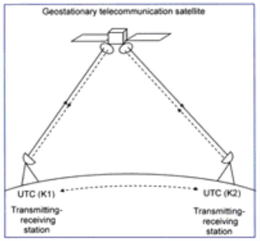
Timing Service

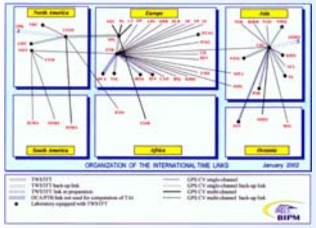
- GNSS CV data
- TWSTFT data

# Time Keeping System Setup



# Tasks of the Precision Timing Facility

→ Maintaining a stable ensemble of clocks in a well controlled environment;

→ Measuring the time offsets of all the clocks compared to the master clock through the local measurement system;

→ Galileo System Time (GST) computation;

→ Galileo System Time steering towards TAI through the steering correction provided by the external Time Service (capability of being autonomous from TSP for 10 days);

→ Provide Galileo System Time to the orbit determination and time synchronisation process.

→ Compute GGTO (GPS to Galileo Time Offset) with accuracy 5 ns (2 sigma) over any 24 hours

# Tasks of the Timing Service

The external Time Service is in charge of:

→ Operating the daily links to UTC(k) laboratories required for the determination of TAI, the periodic calibration of the equipment and remote control facilities, etc.;

→ Performing the data analysis of all the measurements GST-UTC(k);

→ Developing and operating the $TAI_p$ prediction algorithm;

→ Providing Galileo with the daily predicted value of ($TAI_p$-GST) time and frequency offset and the daily steering correction;

→ Interfacing with the BIPM by sending the internal clock data and GST-UTC(k) and receiving from BIPM the Circular T ($\text{GST-UTC(k)}_{old}$);

→ Providing data exchange under request from Galileo Control Segment (TWSTFT and CV);

→ Provision of an extended scientific activity, in collaboration with the leading European laboratories, for obtaining an improved accuracy of GST (better than the specifications) and matching the present and future accuracy of the USNO time scale.

# Main Reasons to involve an External TS

→ Cost savings are expected for the Galileo FOC core infrastructure by simplifying the timekeeping system through outsourcing of the metrological timekeeping to an external Time Service, and relying on its external infrastructure.

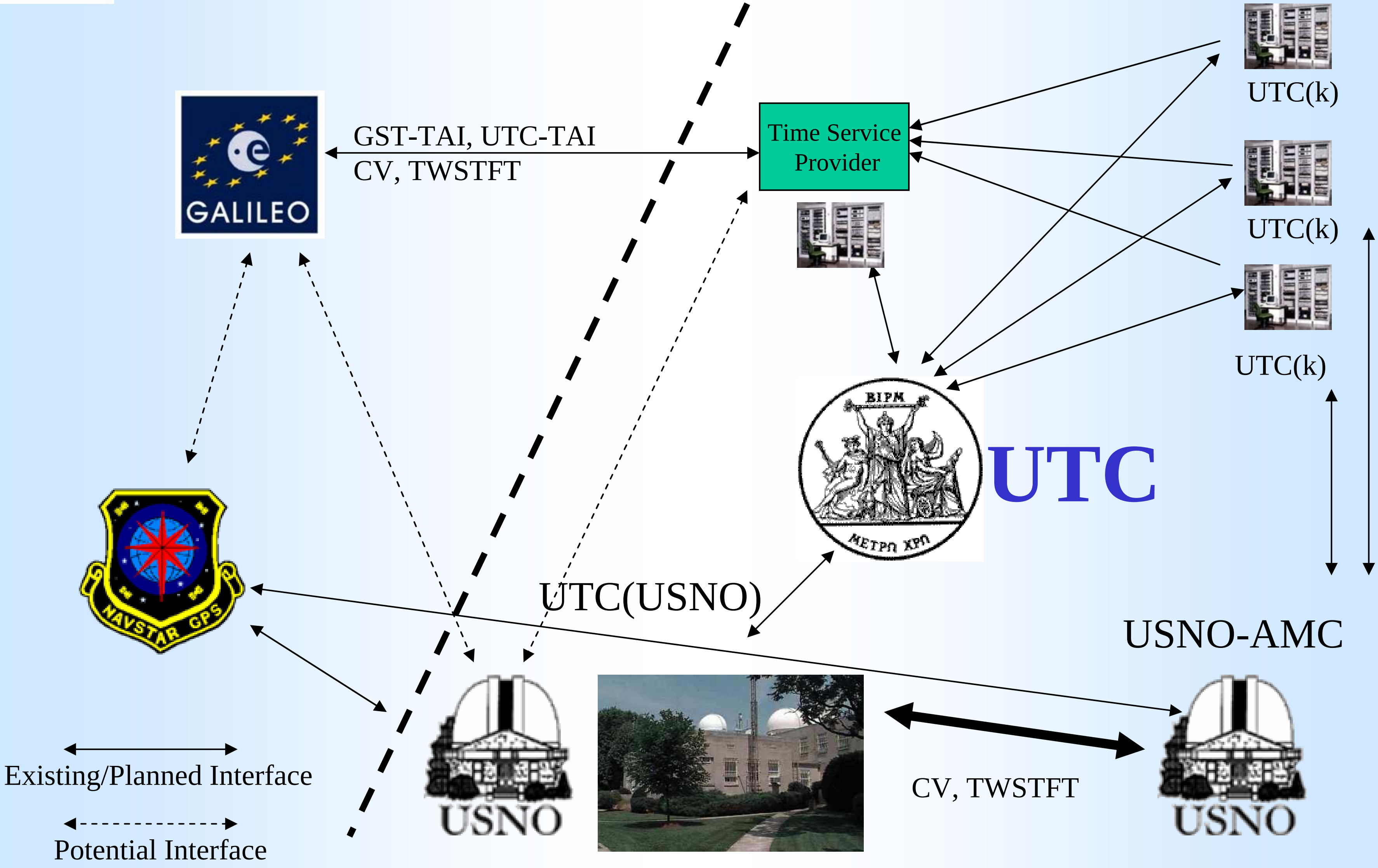
→ It will enable institutional national timing labs and commercial providers to find the best approach for UTC dissemination with the Galileo FOC system.

→ Scientific and market aspects can be better addressed (i.e. in the performance area).

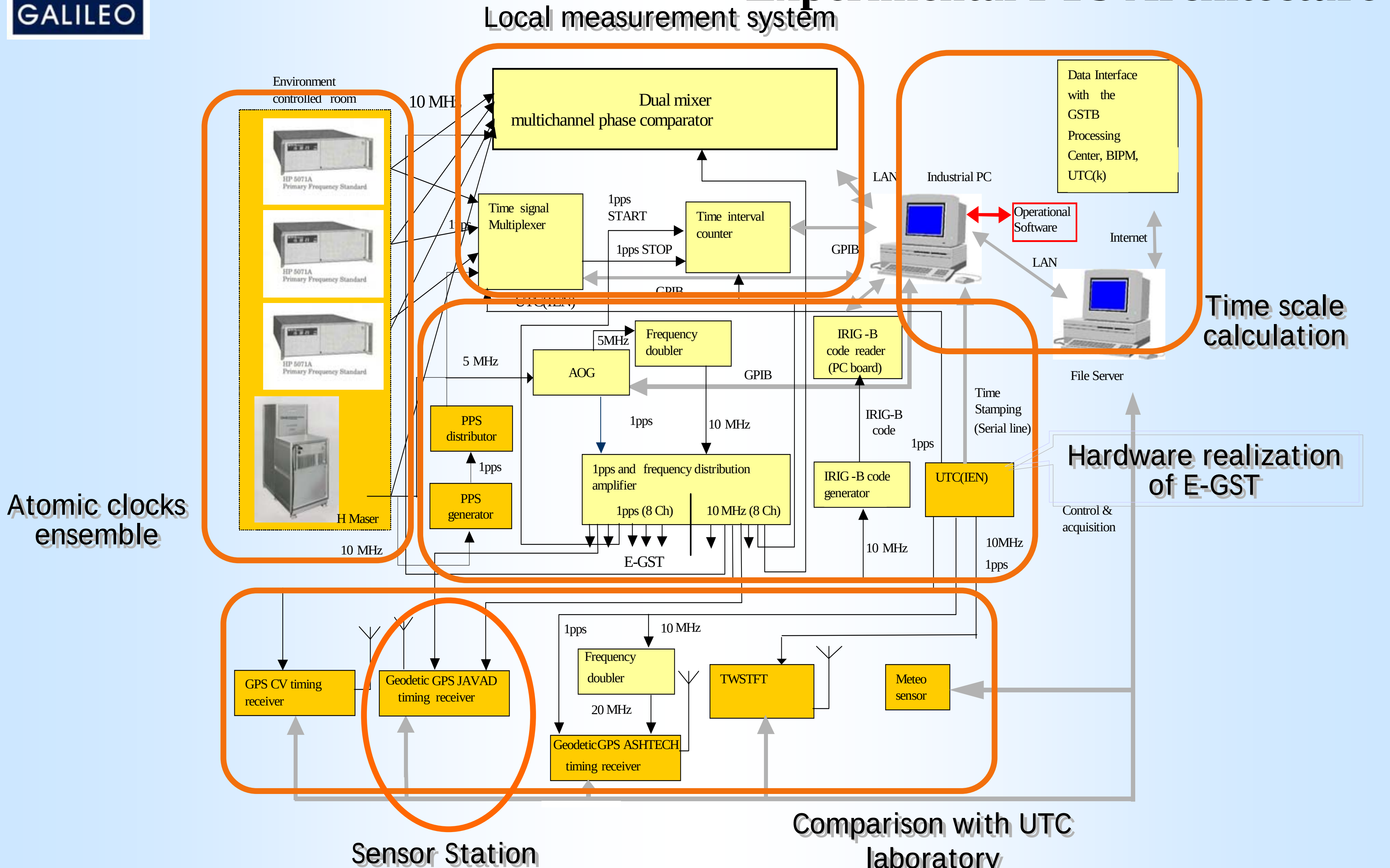
→ It further enables to continuously improve the UTC timing service of Galileo without frequent changes of the core infrastructure (i.e. new and better clock, new UTC prediction algorithms) and thus, to better face the comparison with GPS modernisation initiatives.

→ The approach contributes to the creation of services with Galileo.

# GPS/Galileo Interface to UTC Time Services

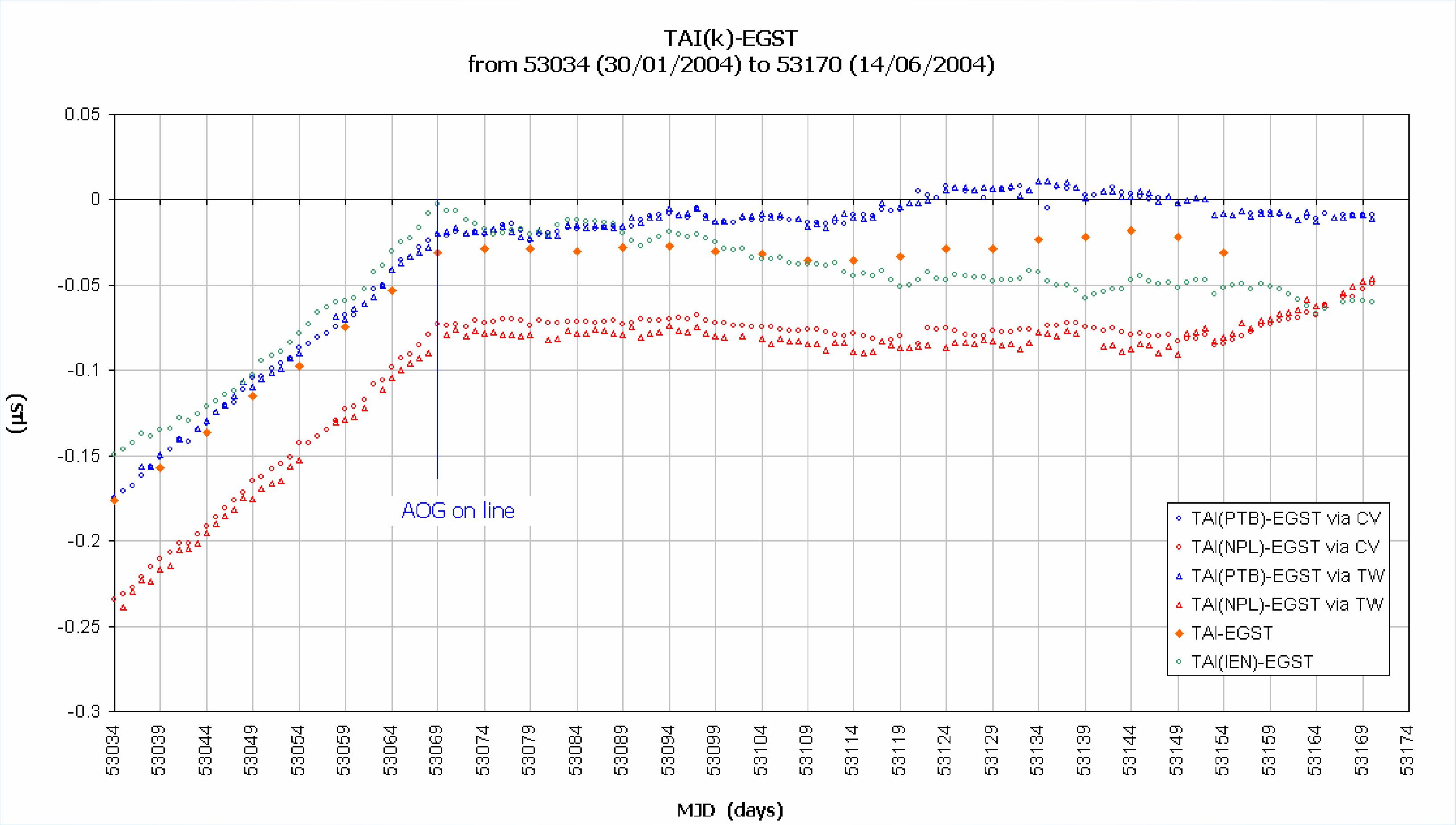


# Experimental PTS Architecture

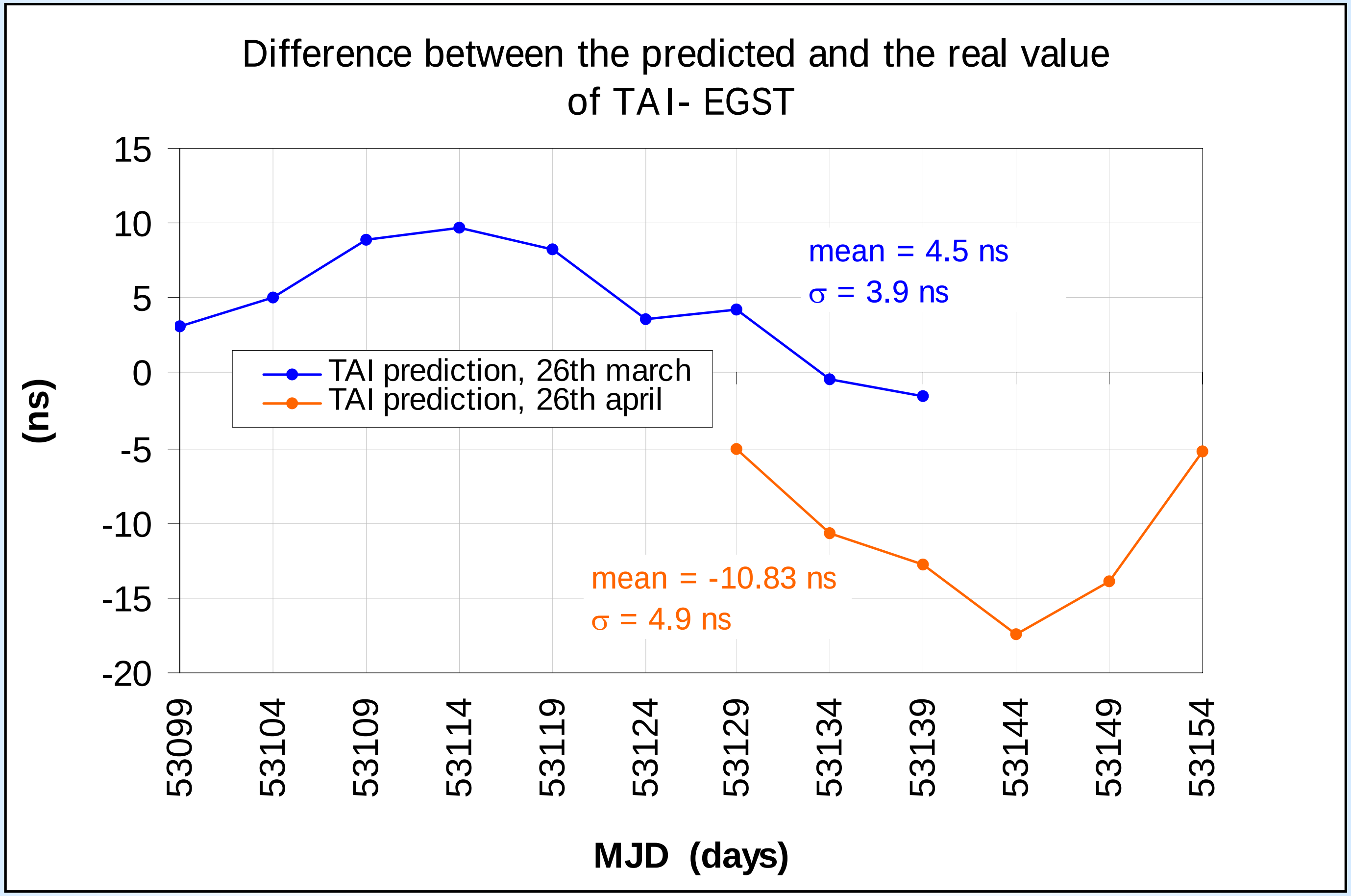


# E-PTS Major Elements


# Present E-PTS Performance



# Present E-PTS Performance




Preliminary results…Time will show….

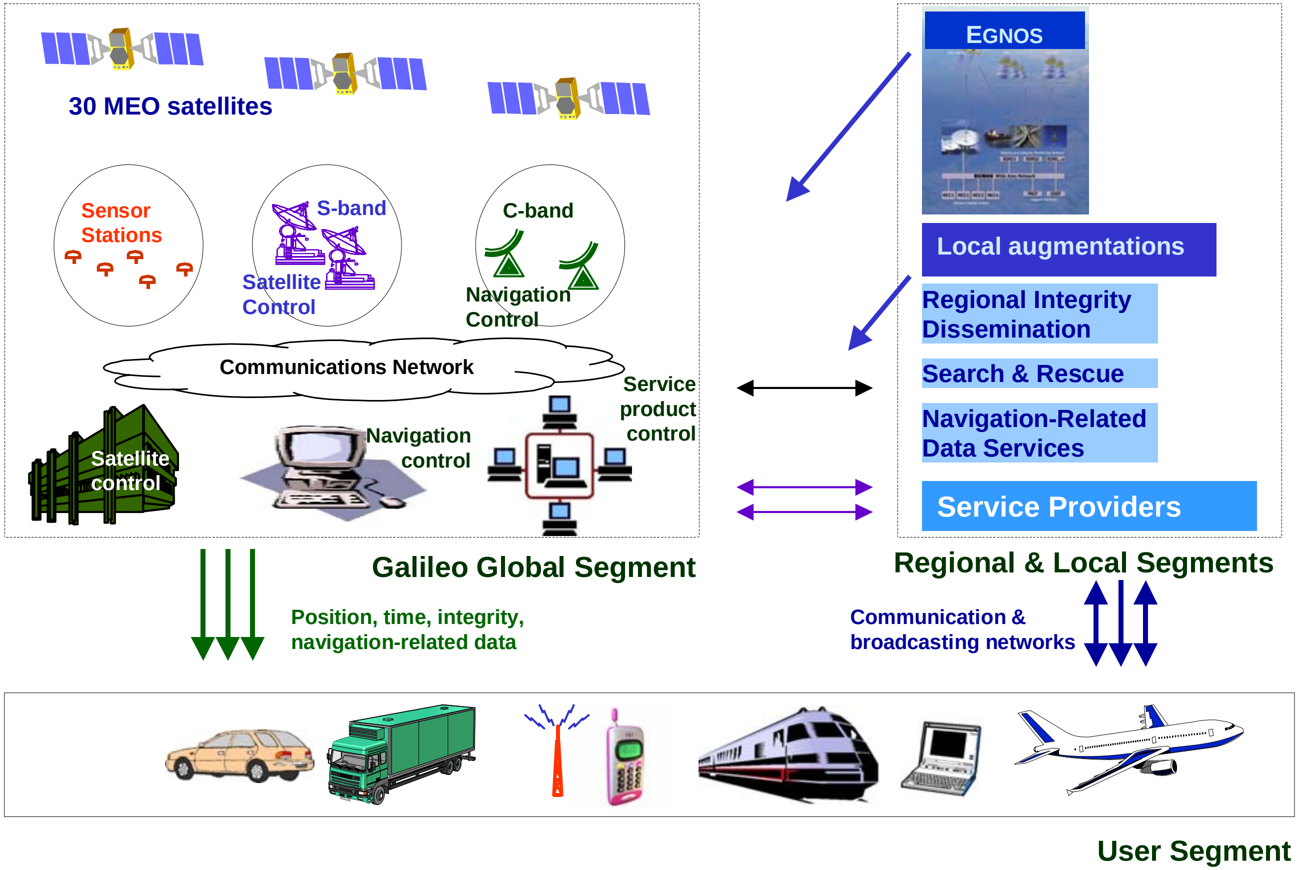
# …Main Timing Issues to be tackled…

- Procure PTF for IOV to verify GST / TAI predication performance; TSP functionality to be addressed by a UTC-lab
- GGTO I/F setup for IOV
- GEO-Transponder lease/use for TWSTFT
  - needed for Interface Galileo - TSP/UTC(k)
  - GGTO
  - Internal PTF-PTF in FOC
- TSP establishment (institutional) for FOC
- BIPM issues (incl. of Galileo clocks, …)

# Annex

## …Introduction to Galileo Architecture and Development Status…

# Galileo Outline Architecture



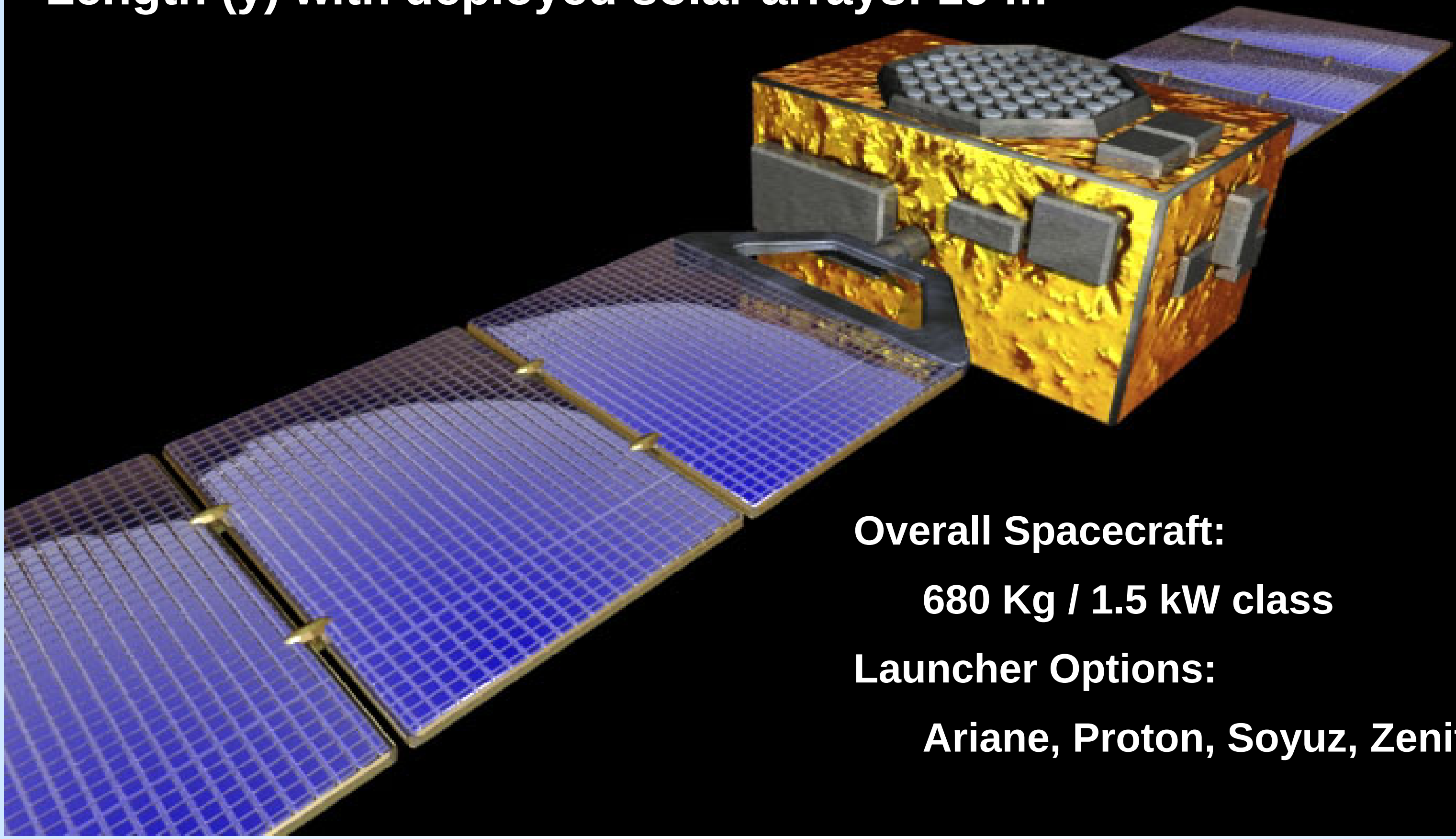
## GALILEO Spacecraft

**Navigation payload: ~130 Kg / 900 W**

**SAR transponder: ~15 kg / 50 W**

**Dimensions: 2.5 x 1.2 x 1.1 m$^3$**

**Length (y) with deployed solar arrays: 19 m**



**Overall Spacecraft:**

**680 Kg / 1.5 kW class**

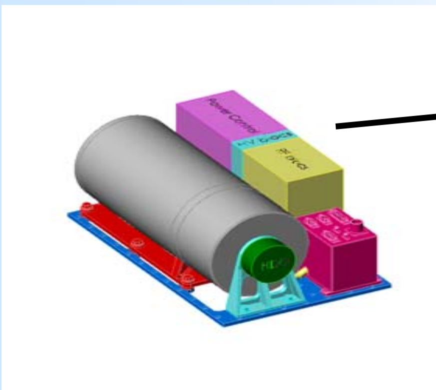
**Launcher Options:**

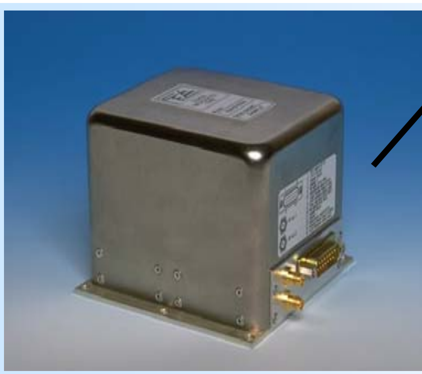
**Ariane, Proton, Soyuz, Zenit**

# On-board Atomic Clocks

## Passive Hydrogen Maser

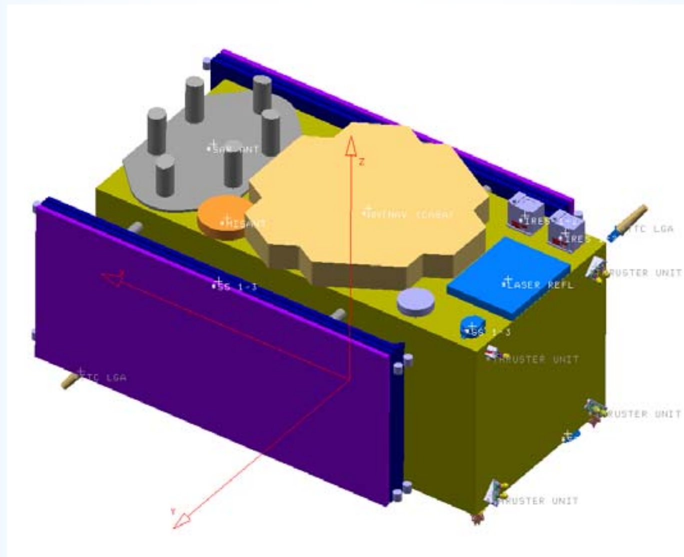
**15 Kg mass**
**70 W power**





## Navigation P/L:

**130 Kg / 900 W**



## Rubidium Atomic Frequency Standard

**3.5 Kg mass**
**30 W power**

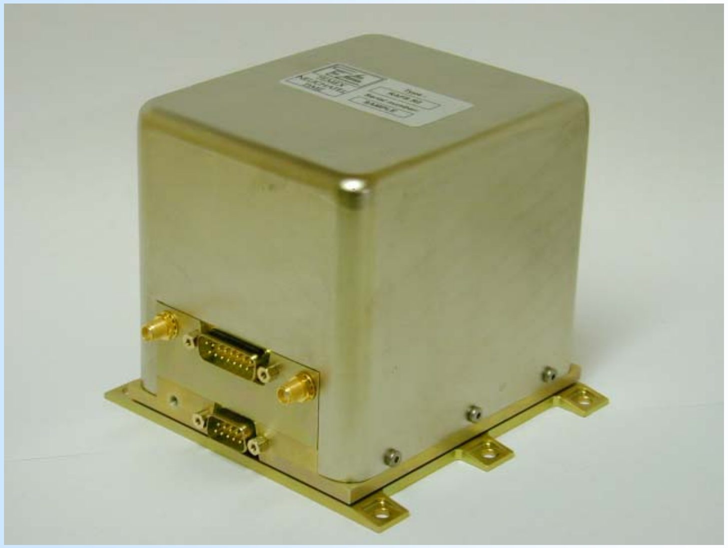
### Types of Atomic Clocks

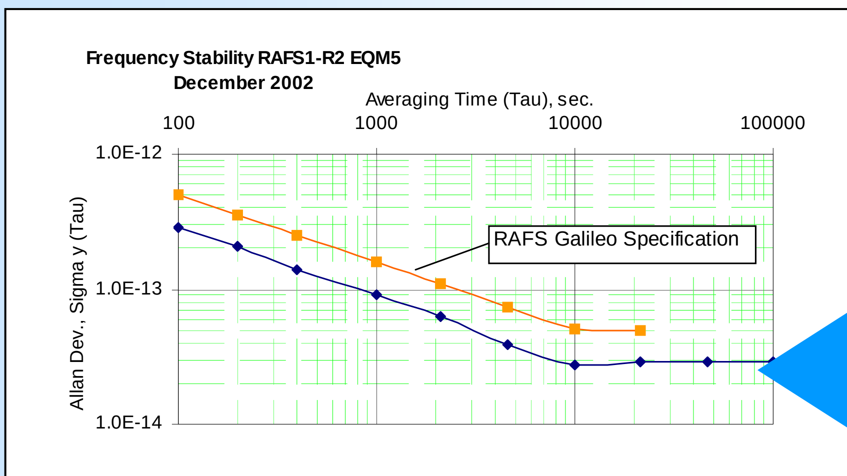
**Rubidium Clock**
- Cheaper and Smaller
- Better short-term stability (European RAFS s=5.0*$10^{-14}$ at 10000 sec)
- Subject to larger frequency variation caused by environment conditions

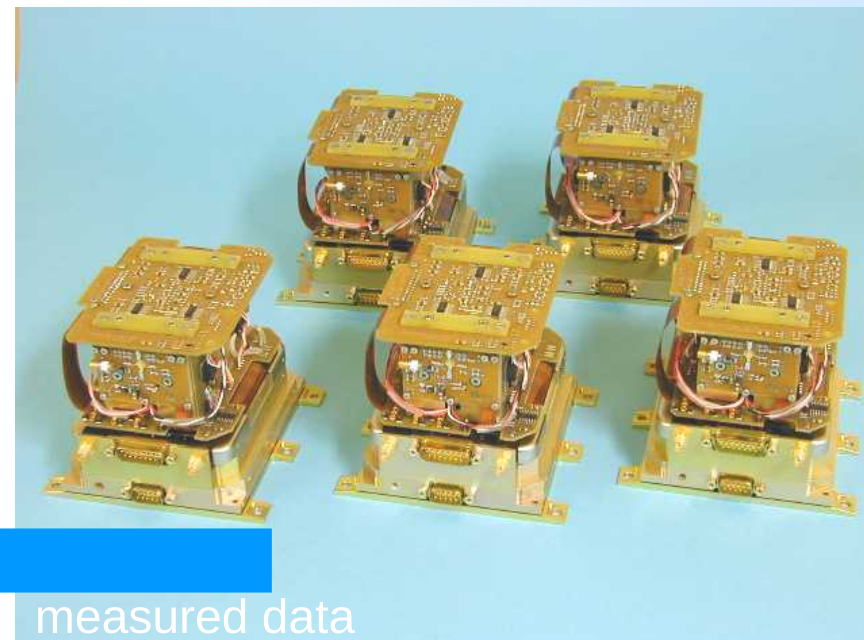
**H-Maser Clock**
- outstanding short-term and long term frequency stability ($10^{-15}$)
- frequency drift

**Caesium Clock**
- Better long-term stability ($10^{-14}$)
- shorter life time
- not used in Galileo

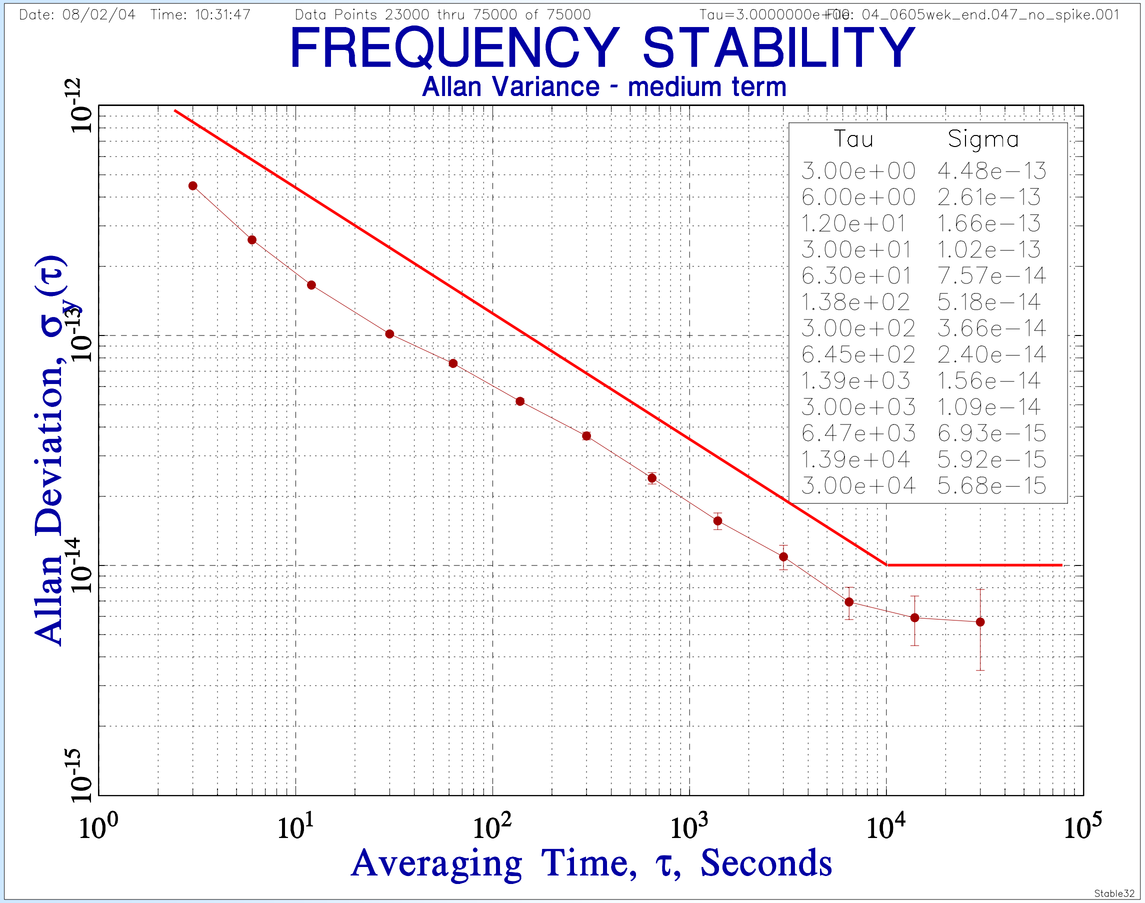
# Rubidium Atomic Frequency Standard (RAFS)

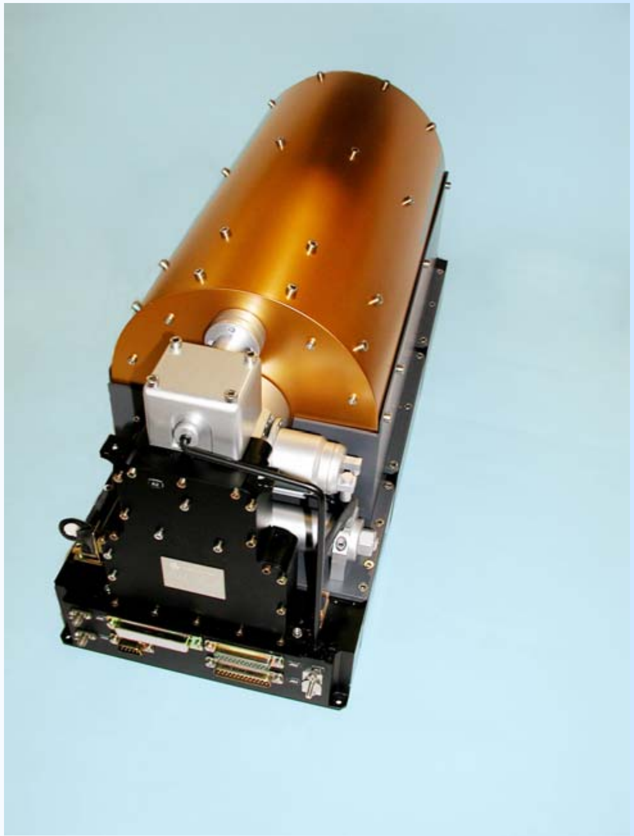




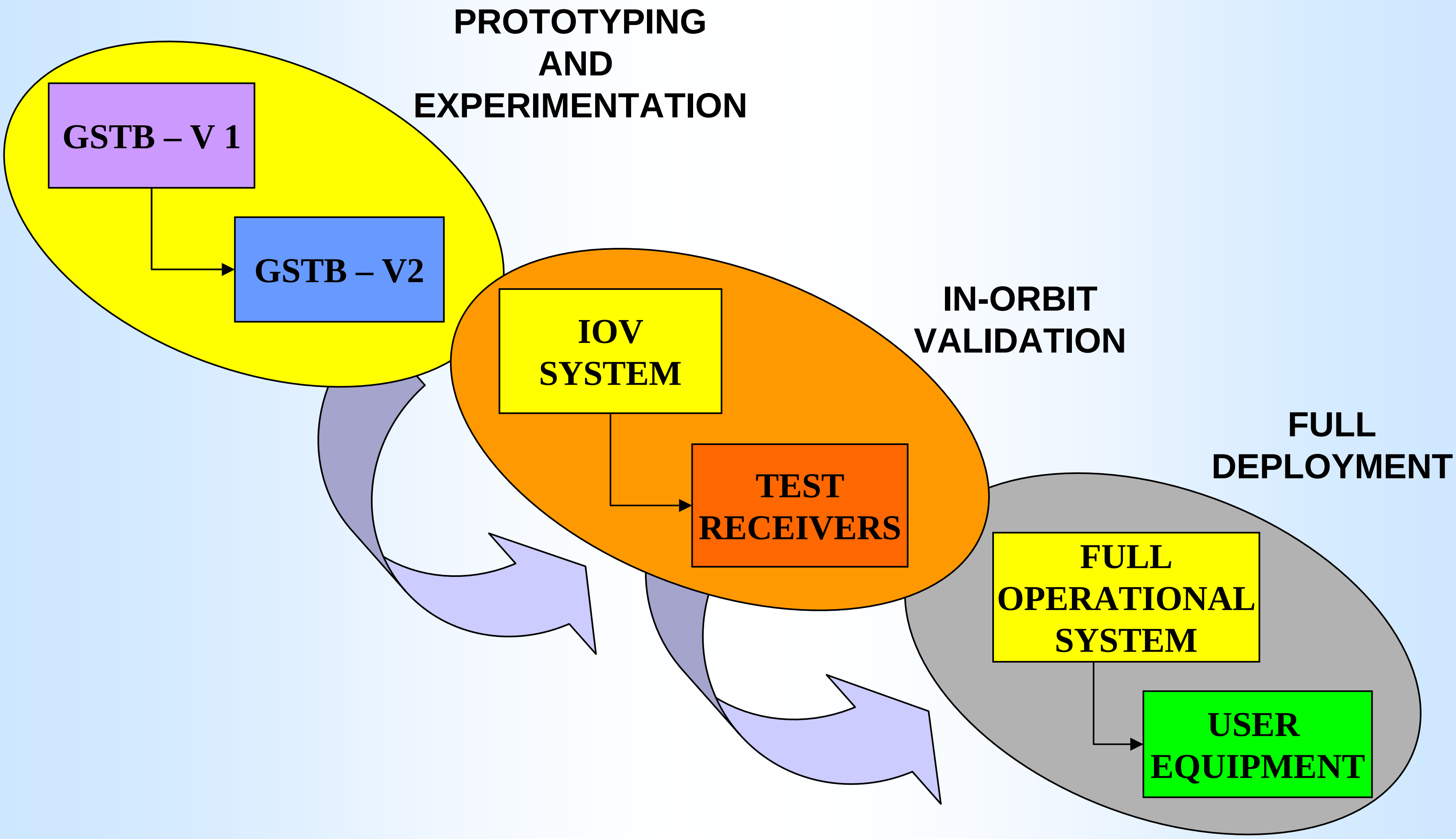



# H-Maser Atomic Clocks



## Galileo Implementation Steps

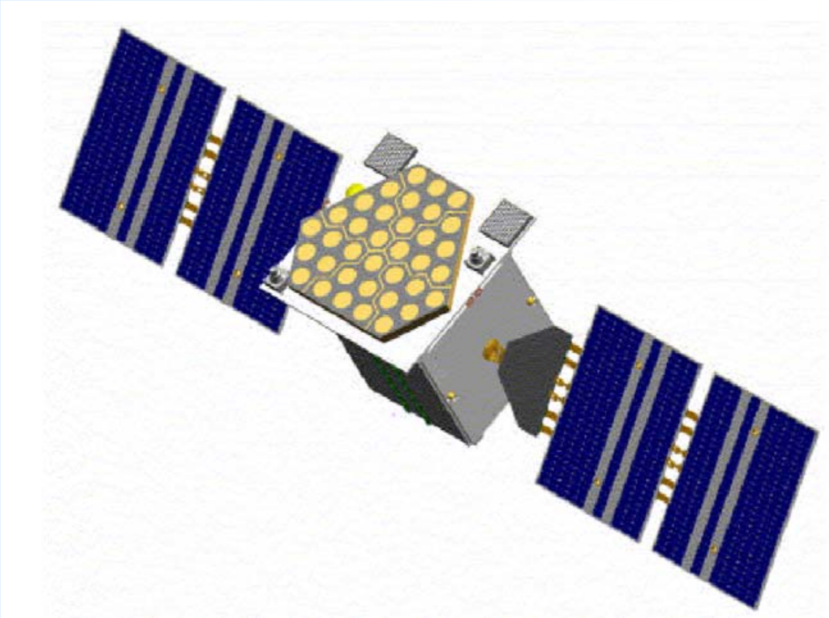


## Galileo Experimental Satellites

- First European navigation satellite.
- First European satellite in MEO orbit.
- Europe will meet requirements for Galileo frequency filings.
- The H-maser clock will be the more stable clock ever flown in space.
- Launch planned by the end of 2005.

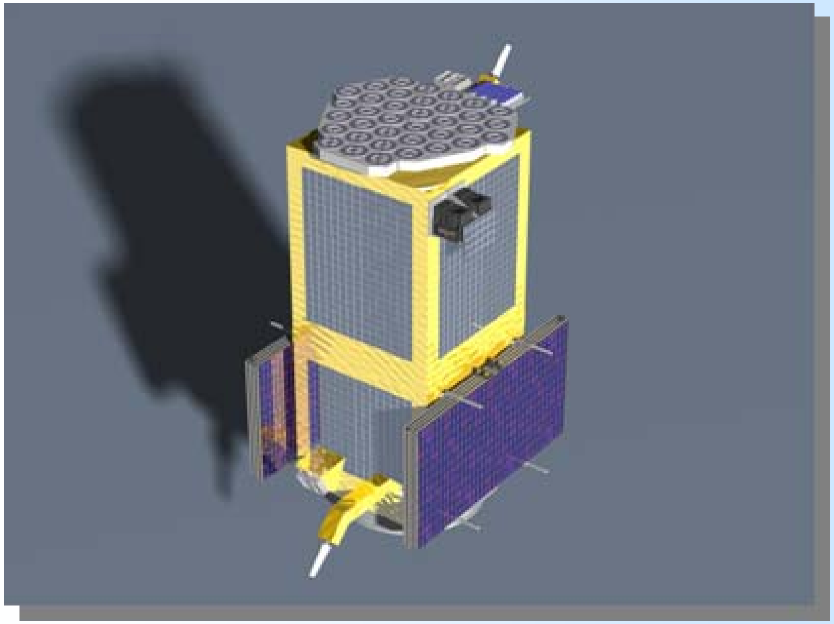
# GSTB-V2 Satellites

## V2A - SSTL



- Lift-off mass 450 kg
- Power demand 660 W
- Stowed Dimensions 1.3 m x 1.74 m x 1.4 m

## V2B – GaIn



- Lift-off mass 523 kg
- Power demand  943 W
- Stowed Dimensions: 0.955 m x 0.955 m x 2.4 m

## Main Achievements to data

- Critical technology developments completed: i.e. clocks
- Two experimental satellites commissioned.
- Contract for GSTB-V2 launchers signed.
- First experimental satellite to be launched by end 2005.
- Ground segment test-bed already developed to experiment with Galileo-like processing algorithms.
- Phase C/D for the development of the in-orbit validation phase (IOV) initiated.